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THE UNITED STIRLING P40 ENGINE FOR SOLAR DISH CONCENTRATOR APPLICATION

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ABSTRACT

The United Stirling P40 engine is a key component in a solar concentrator based energy conversion system, to be demonstrated and tested during 1980-81. This paper reviews the inherent characteristics of modern Stirling engines and focuses on the baseline P40 double-acting engine. This four cylinder engine is the result of extensive component development work at United Stirling in Sweden, and is also playing key roles in other application programs, notably the DOE/NASA Automotive Stirling Engine program. The extent of modifications required for the solar application is reviewed and performance data are predicted. Finally, the potential of an advanced solar Stirling engine is briefly dealt with.

INTRODUCTION

Stirling engines distinguish themselves from most other heat engines by utilizing external heat supply to an internal, closed cycle with gas -- normally helium or hydrogen -- as the working medium. The external heat supply concept and the inherent high thermal efficiency of Stirling engines, facilitating a smaller and thus less expensive concentrator, make them a prime candidate for integration into solar thermal electric power systems.

United Stirling is involved as a contracting partner in the JPL Dish Stirling Solar Receiver technology demonstration project. The objective of that project is to demonstrate, at the JPL Edwards Test Station, a first generation prototype system within one year. The United Stirling contribution to this early demonstration will be to provide a modified version of an existing prototype double-acting Stirling engine. The focus of this paper will be on presenting the P40 engine background and experience.

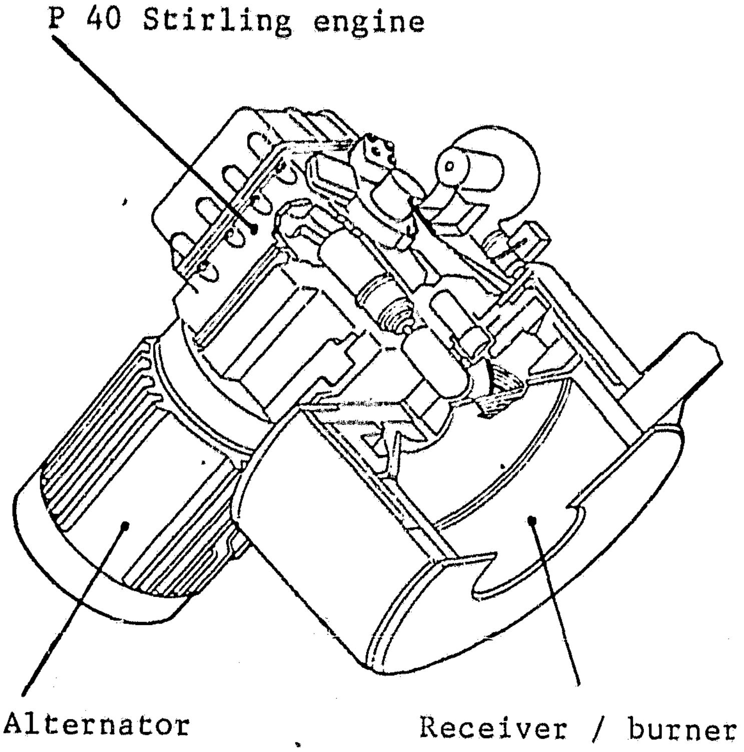

Figure 1. The JPL energy conversion module, to be tested at Edwards.

THE DISH-STIRLING-ALTERNATOR SYSTEM

The concept selected for the Edwards demonstration project is based on utilizing a JPL test bed parabolic concentrator in conjunction with an energy conversion system as shown in Figure 1. A solar receiver and gas combustor unit, to be supplied by the Fairchild Stratos Division, will provide for heat supply to the P40 engine in a hybrid mode, allowing the system to be operated with a constant power output. The P40 engine interfaces with a General Electric induction type alternator, that will deliver 60 Hz, 230/460 volt output to the grid.

The P40 engine was selected for this project primarily because it is a readily available and well proven prototype engine that has a near-term potential for production and that requires only limited modifications for integration into the JPL system. The basic needs for modifications comprise:

-- provision of dry sump lubrication system to allow the engine to be operated in an inverted position;

-- adaptation of the cooling system to the test site external facilities;

-- provision of interfaces with concentrator, receiver, alternator and system controls.

THE BASELINE P40 ENGINE

United Stirling (Sweden) is a research and development company that was established in 1968 for the sole purpose of developing Stirling cycle engines, and to realize their potential as reliable, economical, energy efficient and environmentally acceptable means of energy conversion. The corporate objective is commercial production of Stirling engines.

Early experience at United Stirling included development of a four cylinder, single-acting, rhombic drive type of engine. It turned out, however, that this type of engine was too heavy and complex for most of its intended applications. Subsequently, basically all efforts at United Stirling has been concentrated on development of double-acting engines. This category of Stirling machines have only one piston per cylinder which reduces bulk, weight and number of parts without sacrifice in performance. After a thorough analysis of alternative configurations, a decision was made, four years ago, to concentrate the development on a U-configuration engine, employing parallell cylinders and twin, interconnected crankshafts. The U-configuration represents several advantages, affecting the overall cost and serviceability of the engine:

-- two crankshafts, geared to a common output shaft reduce installation height in a vehicle;

-- parallell cylinders facilitate the machining of cylinder faces in one horizontal set of operations;

-- the parallell cylinders and their straight-forward interfaces with the heater head component, makes inspection and servicing of reciprocating parts easy;

-- a symmetrical arrangement of key components of the hot part of the engine is facilitated by the parallell cylinders and results in improved fluid dynamic conditions.

In its baseline form, and with state-of-the-art gas mean pressure and temperature, the maximum shaft power of the P40 engine is 40 kW at 4000 rpm. The peak point efficiency (measured) is 32%. Both these data refer to hydrogen as the working

medium and with automotive type auxiliaries driven.

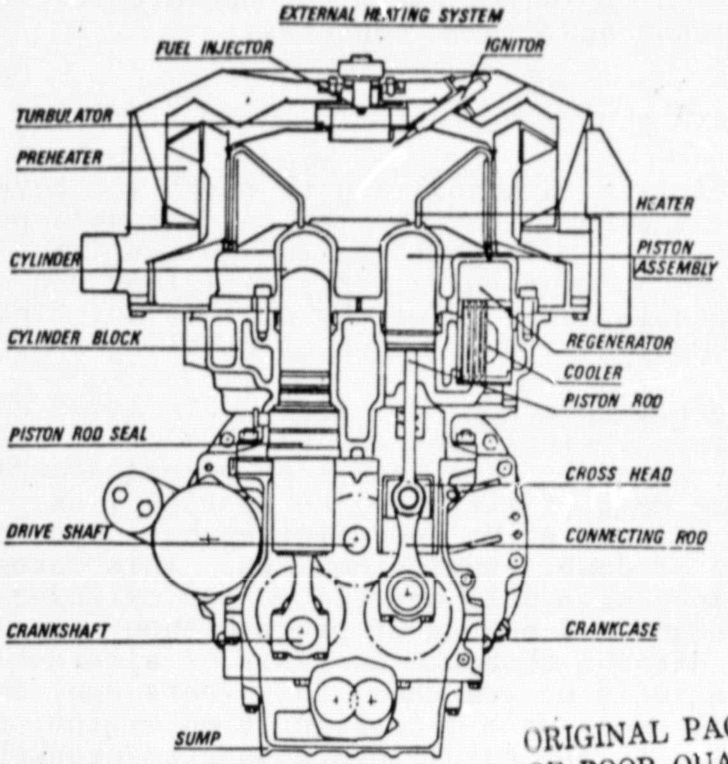

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Figure 2. Cross-section of United Stirling's baseline P40 engine.

A cross-section of the baseline, external combustion type P40 engine is shown in Figure 2. In this case, heat is supplied to the closed cycle from continuous combustion of a liquid or gaseous fuel via the engine heater head, which is a tube-type heat exchanger. Air is being preheated to some 700°C in a metal plate recuperator.

Several conceptual and design features give the P40 engine a potential for a very long time between overhauls. Such unique features are for instance:

- -- inherent low vibration level;
- -- absence of a valve gear;
- -- insignificant deterioration of lubricant due to low temperature and separation of combustion products from the oil.

P40 engines have been subject to extensive tests for about three years, by now. Predominantly, these engines have been used for successive refinement of key components and subsystems like heater heads, piston rod seals, power controls and low emission combustors. More than 5,000 engine hours have been accumulated on the dynamometer so far. Additionally, about 150,000 hours of separate component testing contribute to making the P40 engine a well proven and reliable prototype that is now rapidly approaching the point where extensive field tests is the next logical phase.

The P40 engine is playing a key role as a baseline engine in the DOE/NASA Automotive Stirling Engine (ASE) program. Six P40 engines are hitherto planned for test cell and vehicle evaluation within the ASE program, and an additional twelve P40 engine derivatives will be forth coming in that program. Another current role of a P40 engine is to form the basis for an underwater propulsion system using liquid oxygen combustion of diesel fuel.

PREDICTED PERFORMANCE IN THE DISH SOLAR SYSTEM

Experience from testing baseline P40 engines show an unusually good correlation between calculated and measured performance. Based on that experience, and on receiver inner wall temperatures given below, the following engine performance at 1800 rpm is predicted:

	700°C		800°C	
	He	H_2	He	H_2
Max. power, kW	22.5	24.5	26.0	27.0
Max. efficiency, %	35	37	39	40

POTENTIAL OF AN ADVANCED SOLAR STIRLING ENGINE

Although only few modifications are planned for this first solar power demonstration, performance is predicted to be already competive. The solar application, however, introduces some new operating parameters and system requirements for the P40 operation and time between overhaul, for instance, justifies further development work aiming at prolonging the life of certain components, notably the piston rings and the piston rod seals. The introduction of a ceramic receiver/heater head -- although not regarded as essential for achieving competive performance -- has the potential of substantially reducing the life cycle cost of the engine.

Thus, based on a relatively low-risk development program, an engine time between major overhauls of 30,000 hours seems achievable as a result of a modest advancement program.